ROCK STRENGTH AND ITS MEASUREMENT

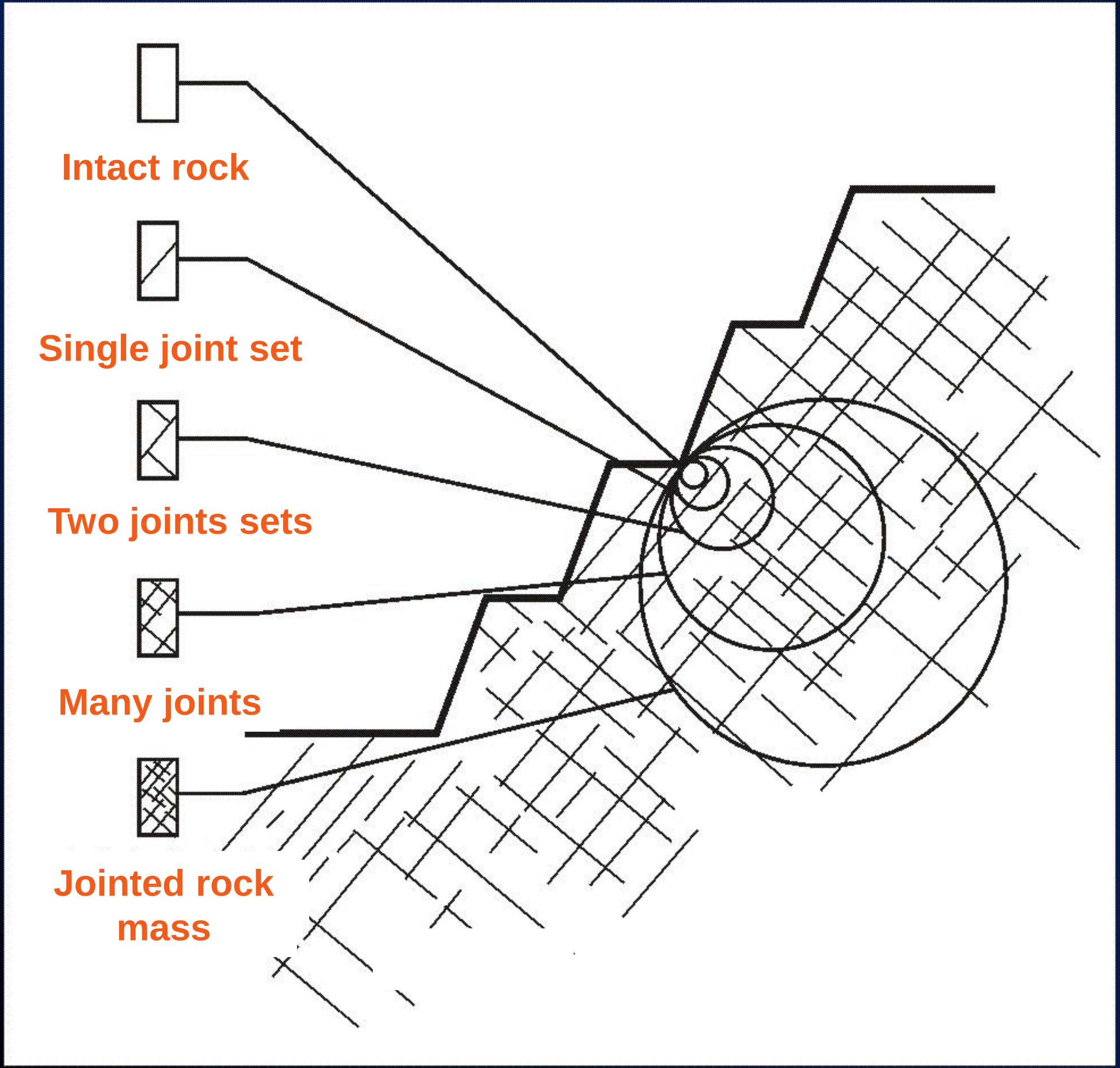
Lesson 3

LESSON 3 - ROCK STRENGTH and Its MEASUREMENT

Learning Outcomes -

- ***Define Mohr-Coulomb Materials – Cohesion and Friction angle;***
- ***Evaluate Shear Strength of Discontinuities;***
- ***Evaluate Shear Strength of Rock Masses;***
- ***Measure intact rock strength – Point Load Test;***
- ***Measure Slake Durability of Intact Rock.***

Rock Strength Categories



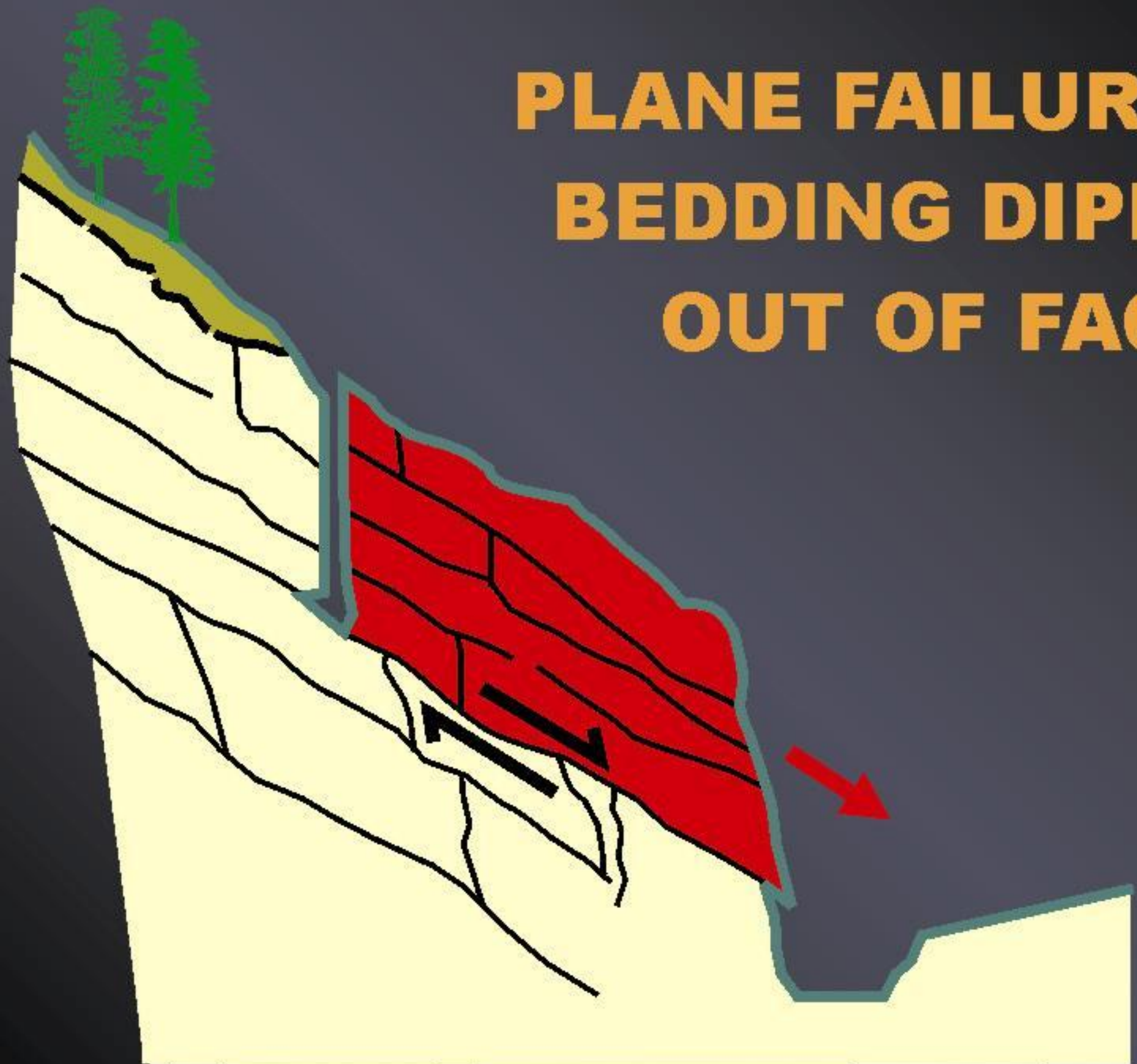
Rock strength categories relate to sample dimensions

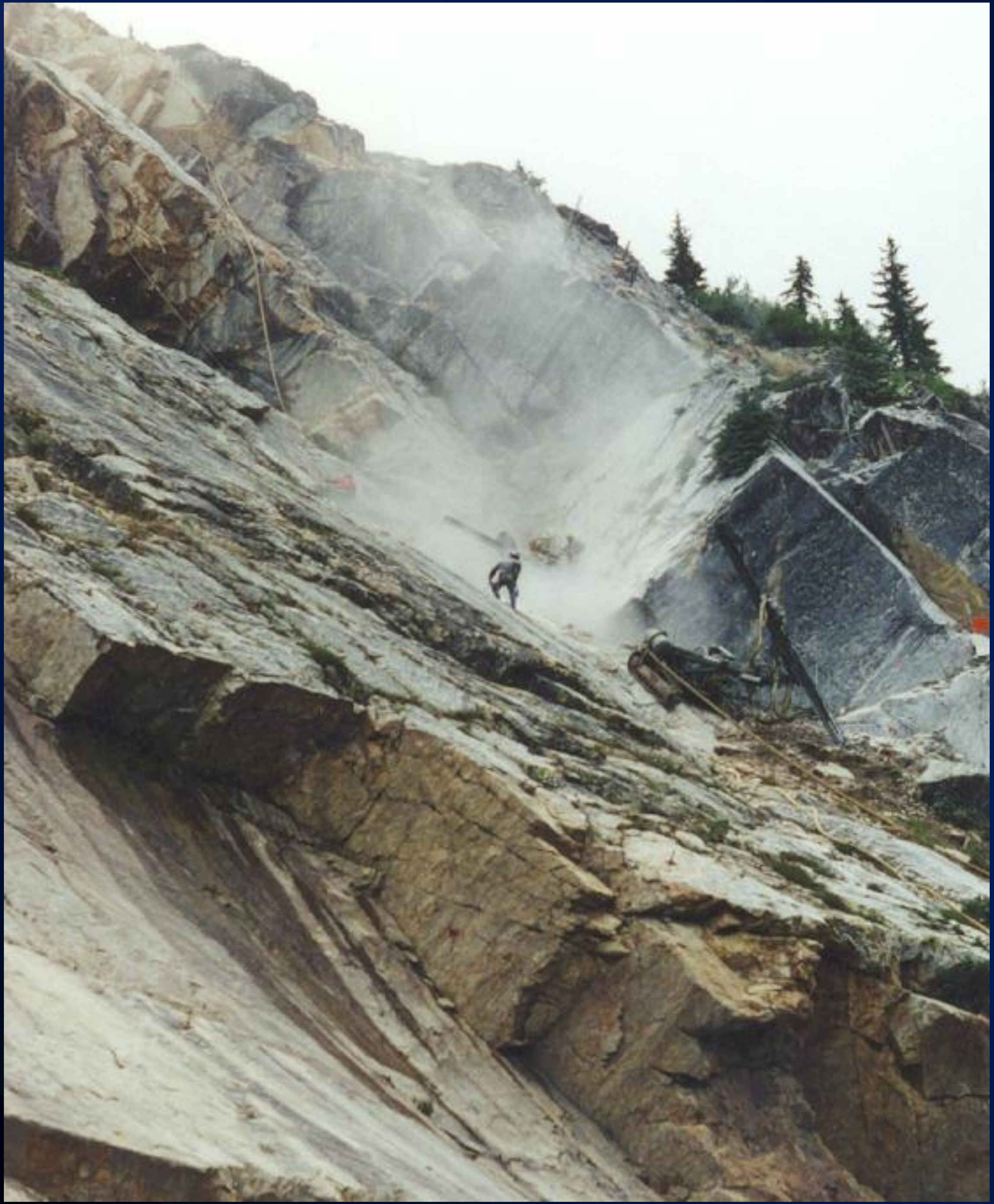
Classes of Rock Mass Strengths

- Strong Rock with Continuous Planes Dipping Out of Face
- Jointed Rock Masses with Few Planes Dipping Out of Face
- Weathered Rock Masses Comprising Residual Soil and Weathered Rock
- Very Weak, Massive Rock Containing Few Discontinuities

Figures 3-2 to 3-4

PLANE FAILURE ON BEDDING DIPPING OUT OF FACE





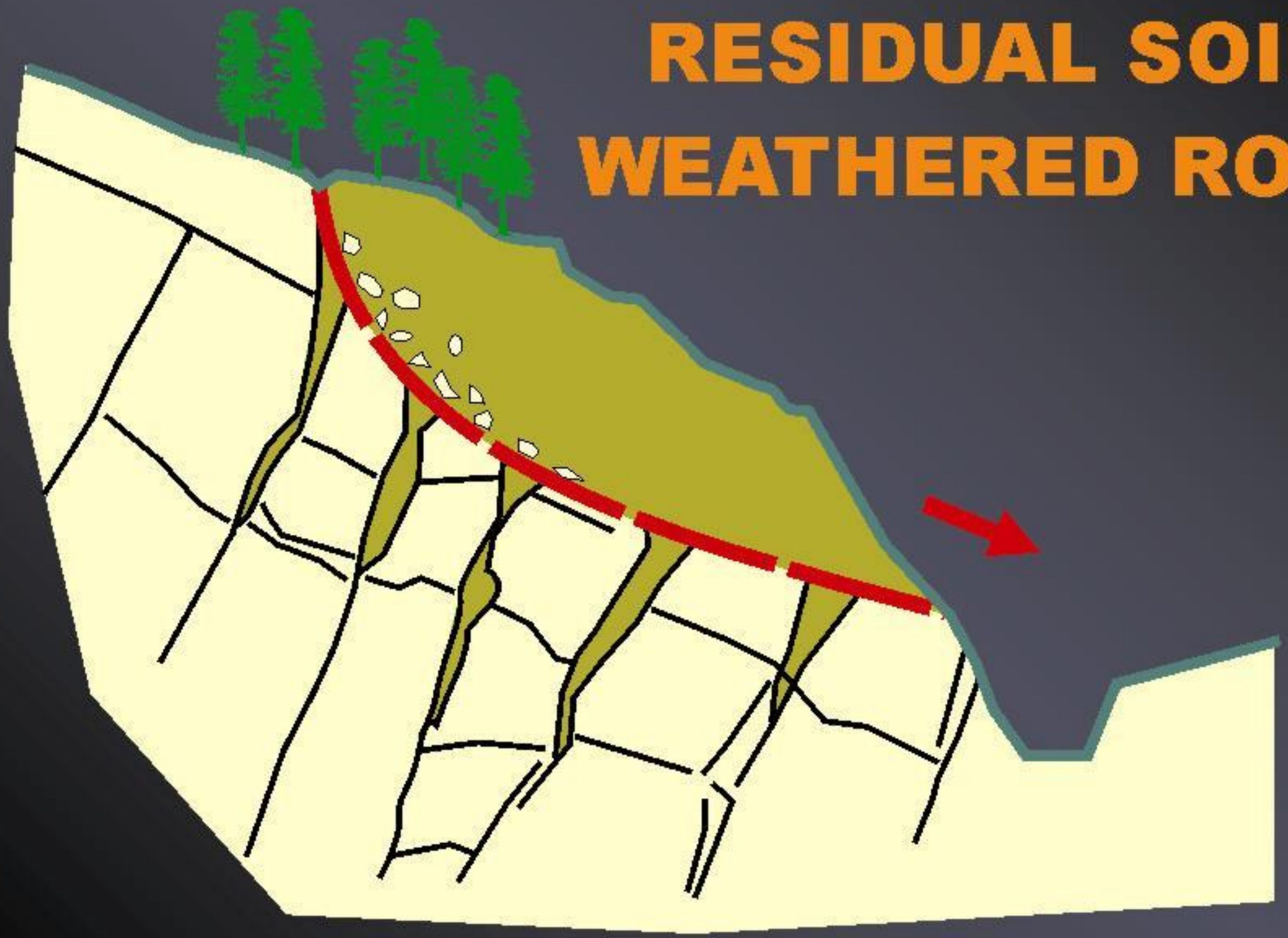
Limestone with persistent bedding planes dipping out of face

SHALLOW FAILURE IN CLOSELY JOINTED ROCK

Basalt with closely spaced, randomly oriented joints

(Oahu, HI)

CIRCULAR FAILURE IN RESIDUAL SOIL/ WEATHERED ROCK

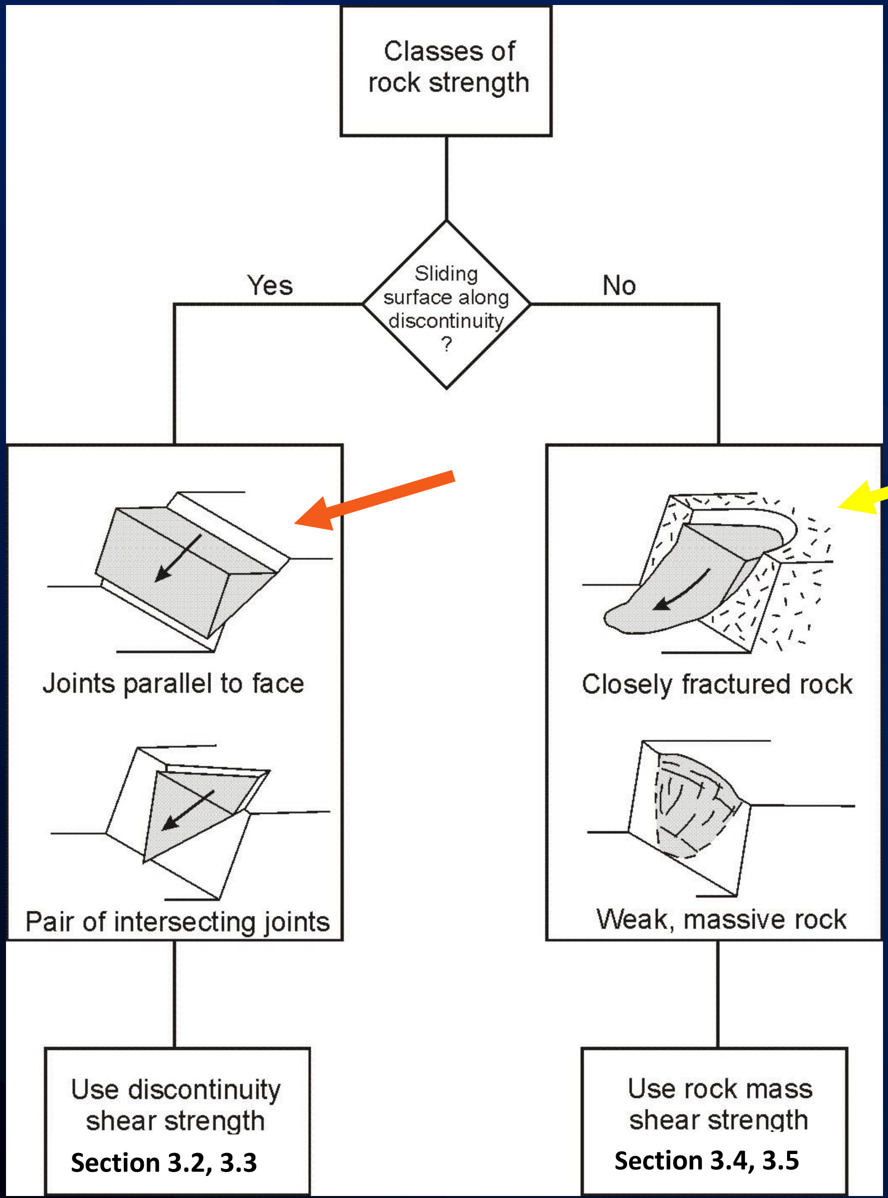


Weathered rock ranging from residual soil (upper) to core stones (lower) ***(AZ)***

STEEP CUT IN VERY WEAK, MASSIVE ROCK

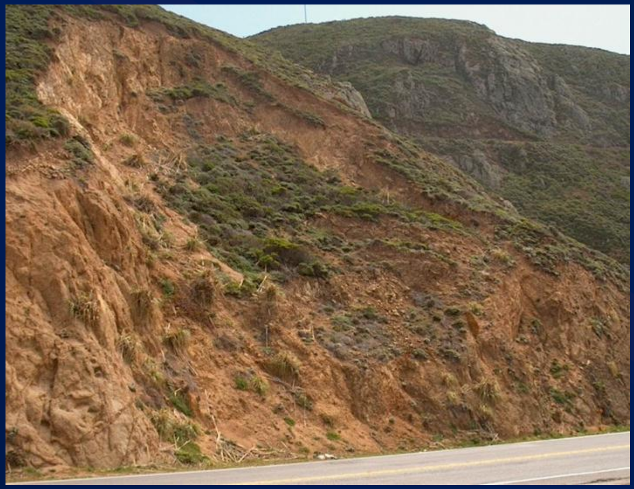
Tuff – very weak, massive rock ***(I-17, Flagstaff, AZ)***

Classification of rock strengths –



Discontinuities

Rock mass



Mohr-Coulomb Materials

- **Shear Strength of Rock Defined by:**
  - *Cohesion (c) and Friction Angle (ϕ)*

- **Shear Strength (σ) on Sliding Surface Given by:**

$$\tau = c + \sigma' \tan\phi$$

Eq: 3-1

where σ' is Effective Normal Stress on Sliding Surface

Types of sliding surfaces

- Discontinuity with Weak Infilling
- Planar, Smooth Discontinuity with No Infilling
- Rough Discontinuity with Roughness Angle i
- Closely Fractured, Strong Rock
- Intact, Weak Rock

Figure 3.5

Relationship Between Shear Strength and Geological Conditions

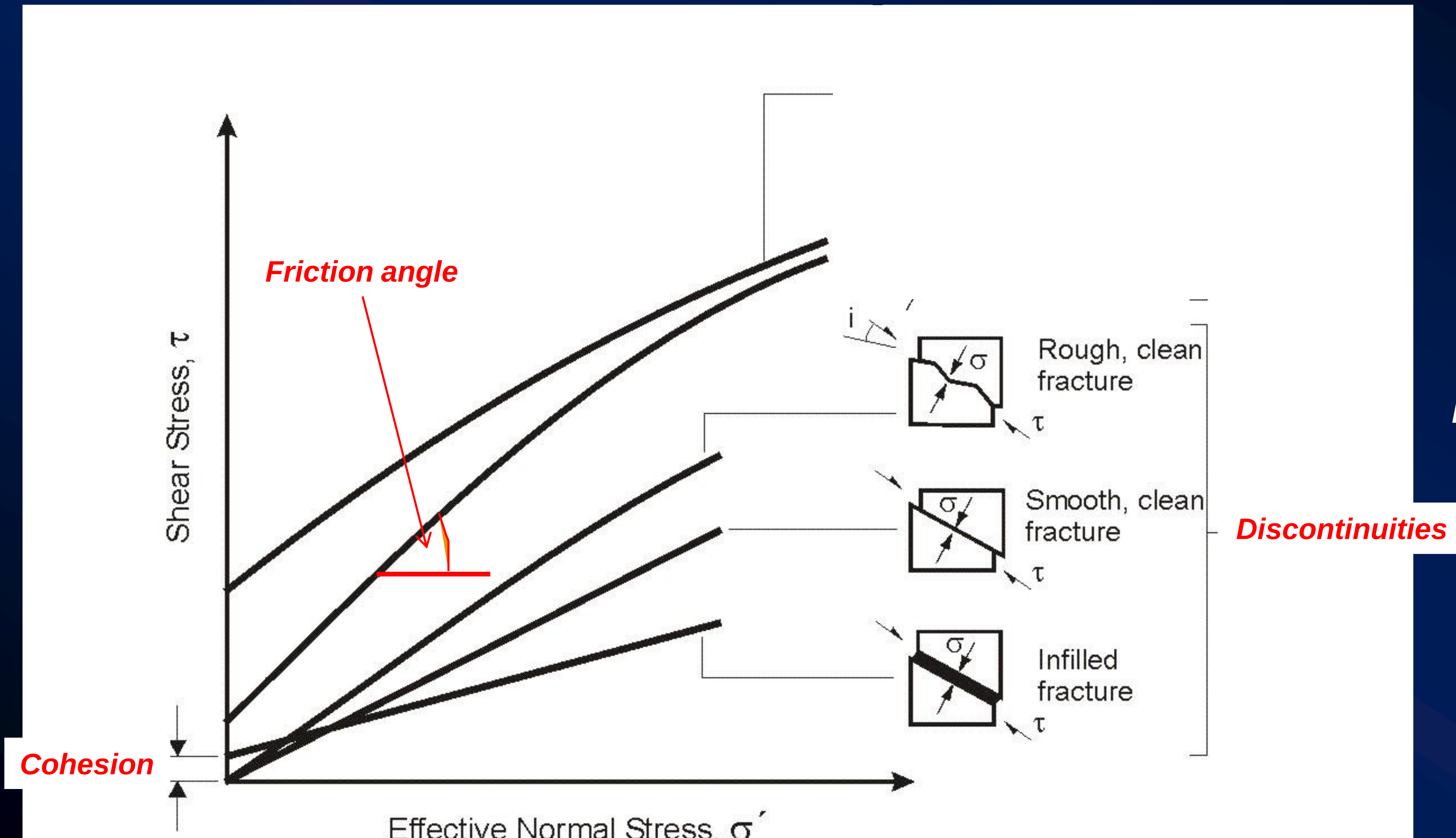


Fig. 3.5

Strength of Discontinuities

- *Irregularity (Shape and Roughness)*
- *Wall Rock Strength*
- *Alteration*
- *Aperture*
- *Infilling*

Rough surface formed by ripple marks

Smooth bedding planes

Effect of Surface Roughness (i) on Friction Angle

- ***Total Friction Angle,***
  $\phi_t = (\phi + i)$

- ***Friction angle diminishes as asperities are ground off with increasing normal stress***

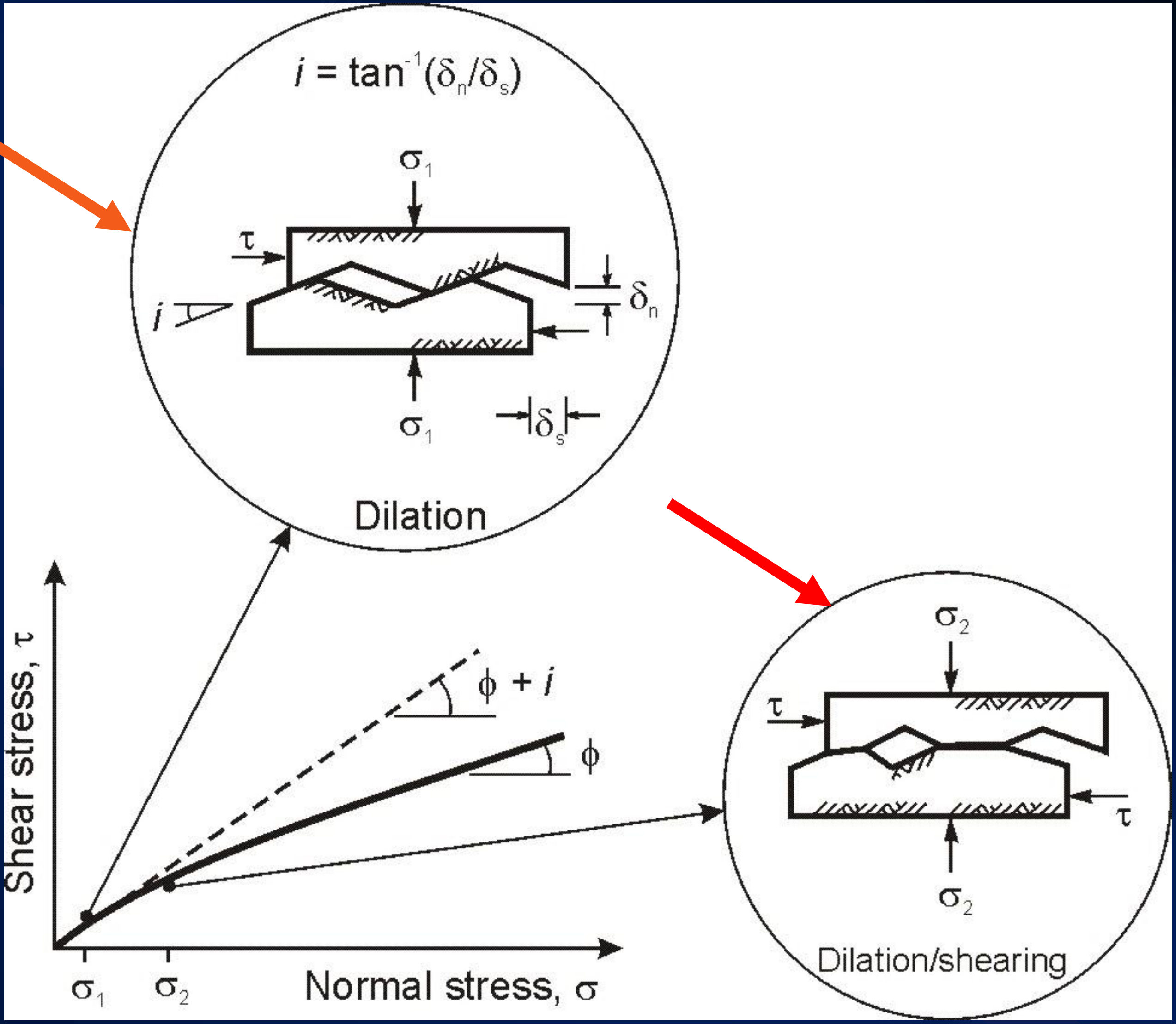
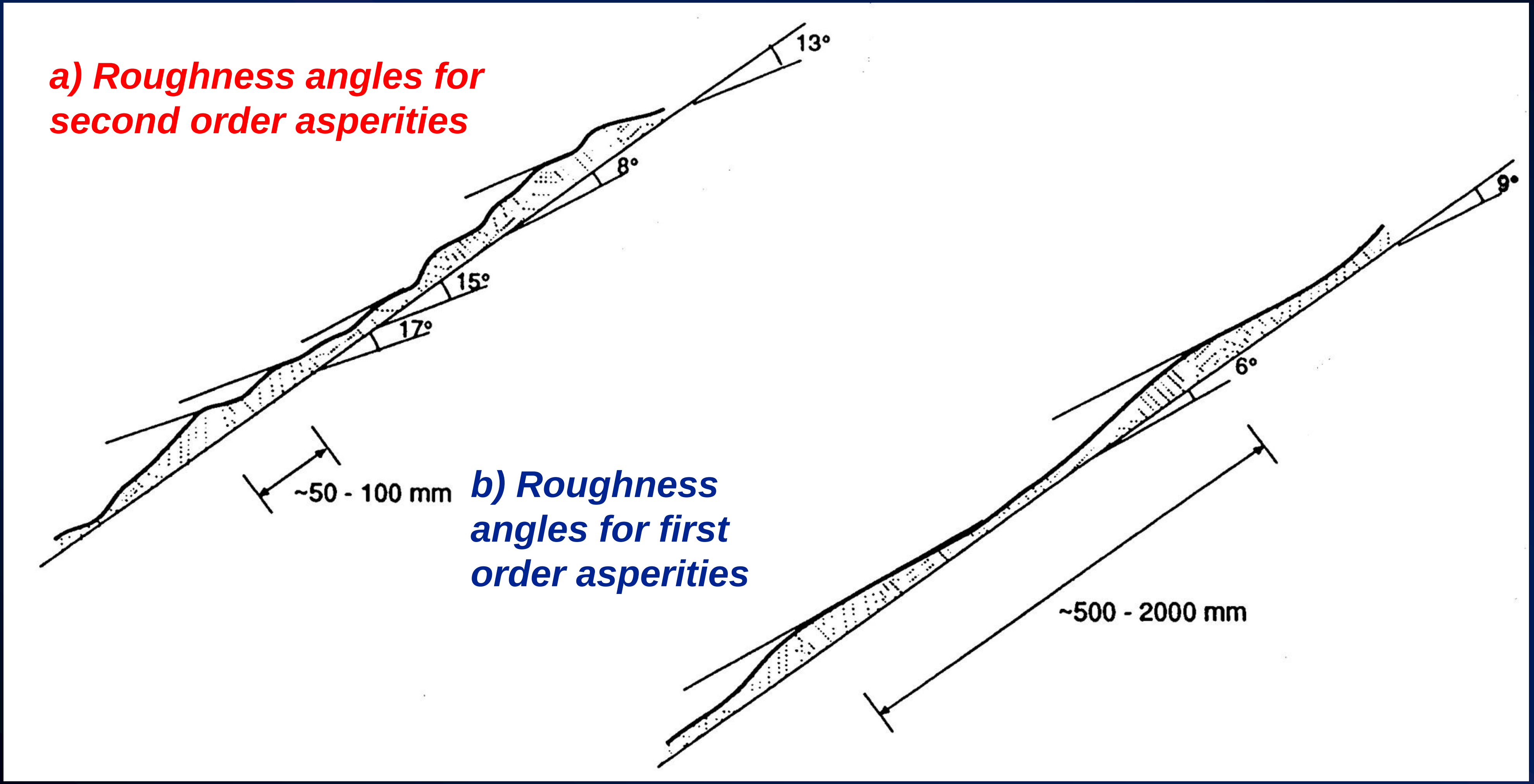


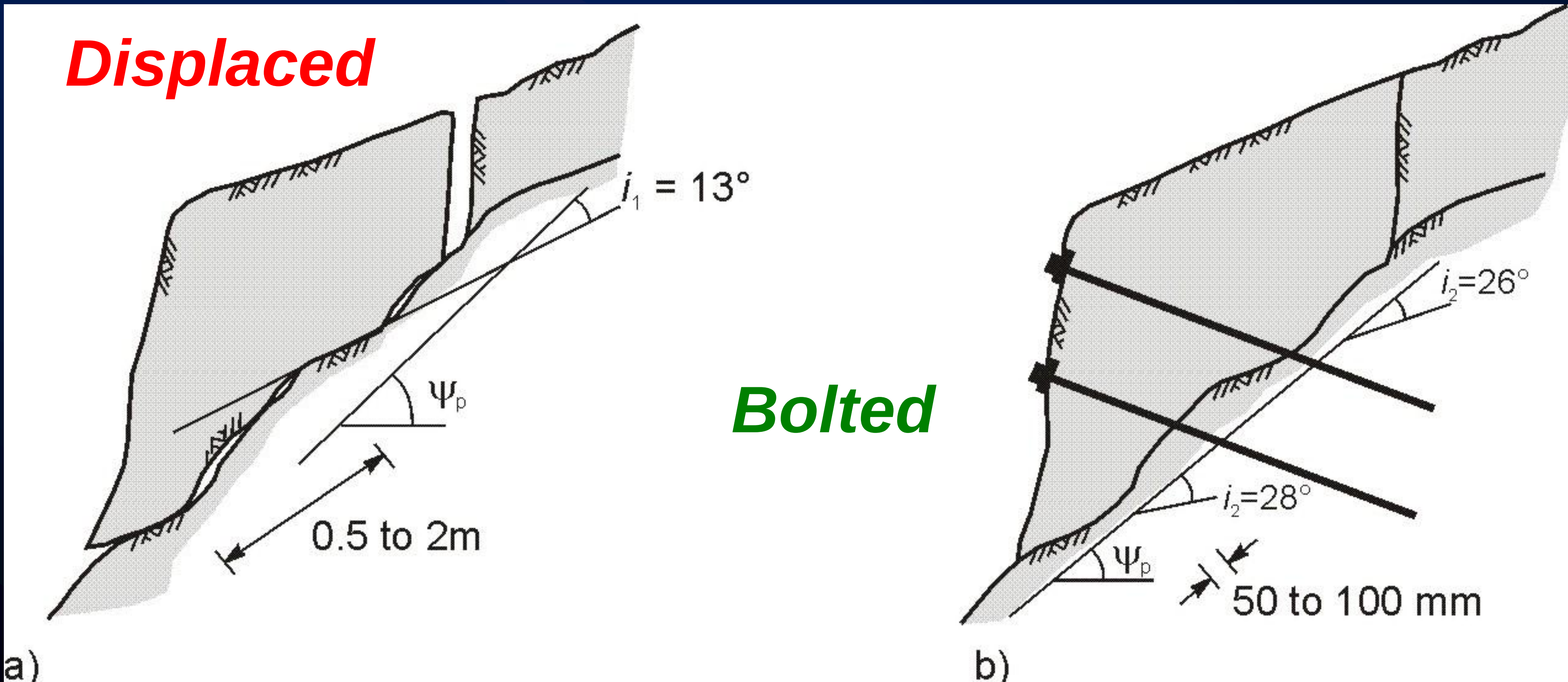
Fig. 3.6

First and Second Order Asperities on Natural Rock Surfaces



Effect of Surface Roughness on Stability

Tensioned rock bolts prevent dilation along potential sliding surface and produce interlock along second order asperities (i_2)



Joint Roughness Coefficient (JRC)

- ***Roughness Angle Decreases with Increasing Normal Stress, (σ') as Asperities are Sheared***

$$\tau = \left[\sigma' \tan(\phi + JRC \log_{10}(JCS / \sigma'))\right]$$ **Eq. 3-3**

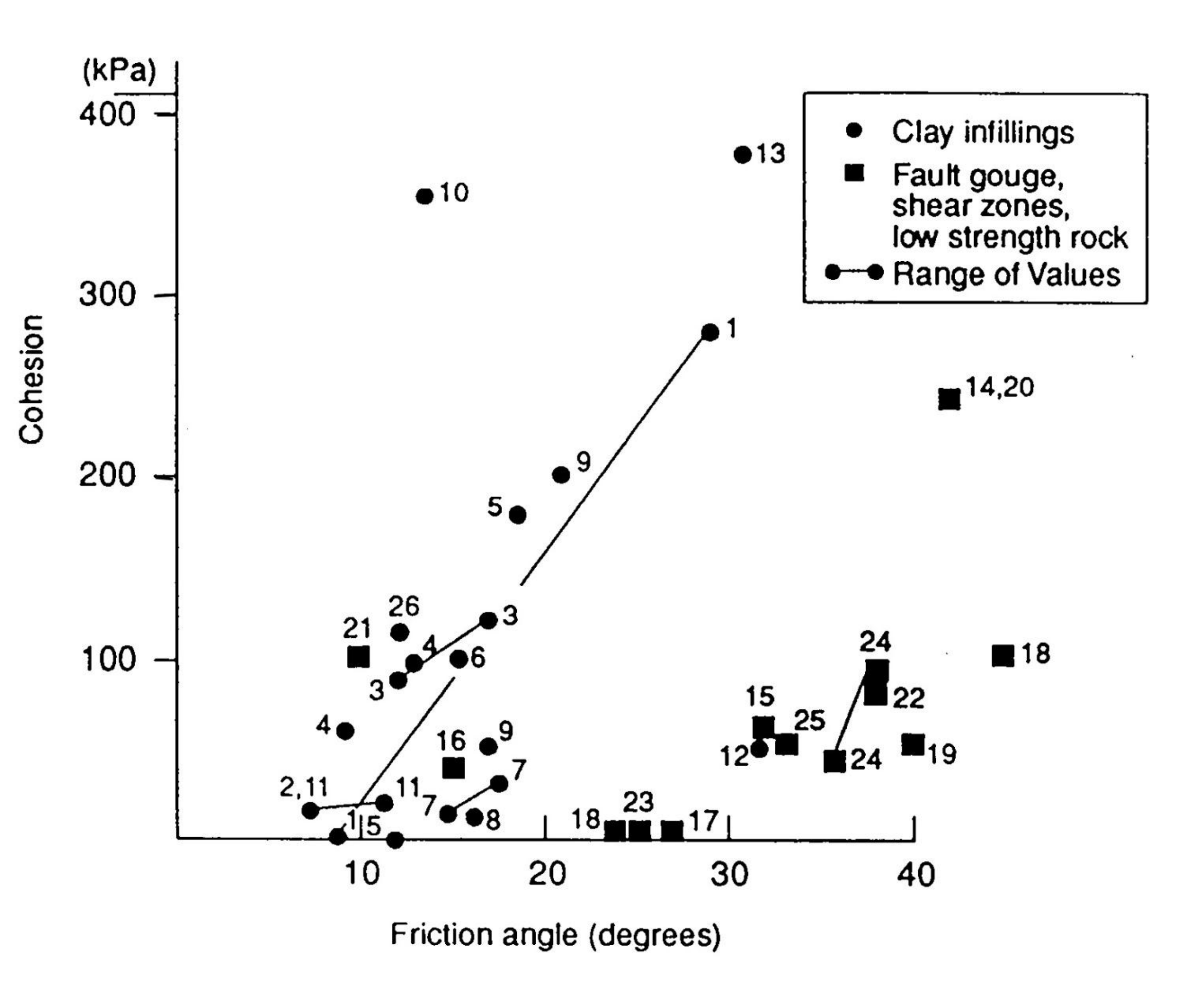
Rough Undulating	***JRC 20***	***e.g. Tension Joints***
Smooth Undulating	***JRC 10***	***e.g. Foliation/Joints***
Smooth Planar	***JRC 5***	***e.g. Bedding***

Shear Strength of Filled Discontinuities

- ● Clay infillings
  $\Phi < \sim 18^o$

- ■ Fault gouge (granular)
  $\Phi \sim 22^o$ to 40^o

Fig. 3.11



Fault infilling

Direct Shear Tests of Discontinuities in Core to Determine Friction Angle

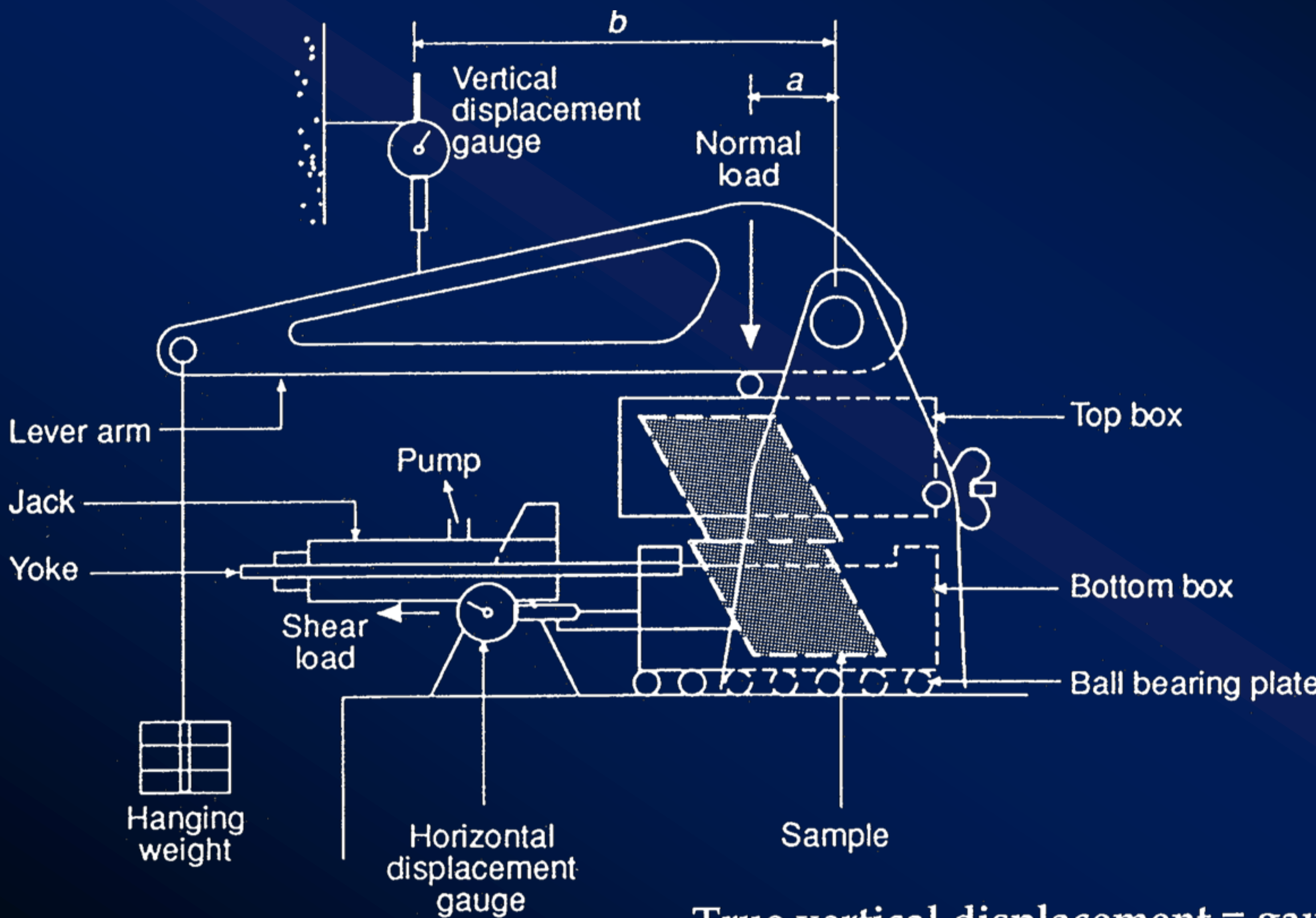


Fig. 3.13

True vertical displacement = gauge reading × (a/b).

Student Exercise - 4

- *Analysis of direct shear test results*

Student Exercise No. 2A

Shear Strength of Fractured Rock Masses

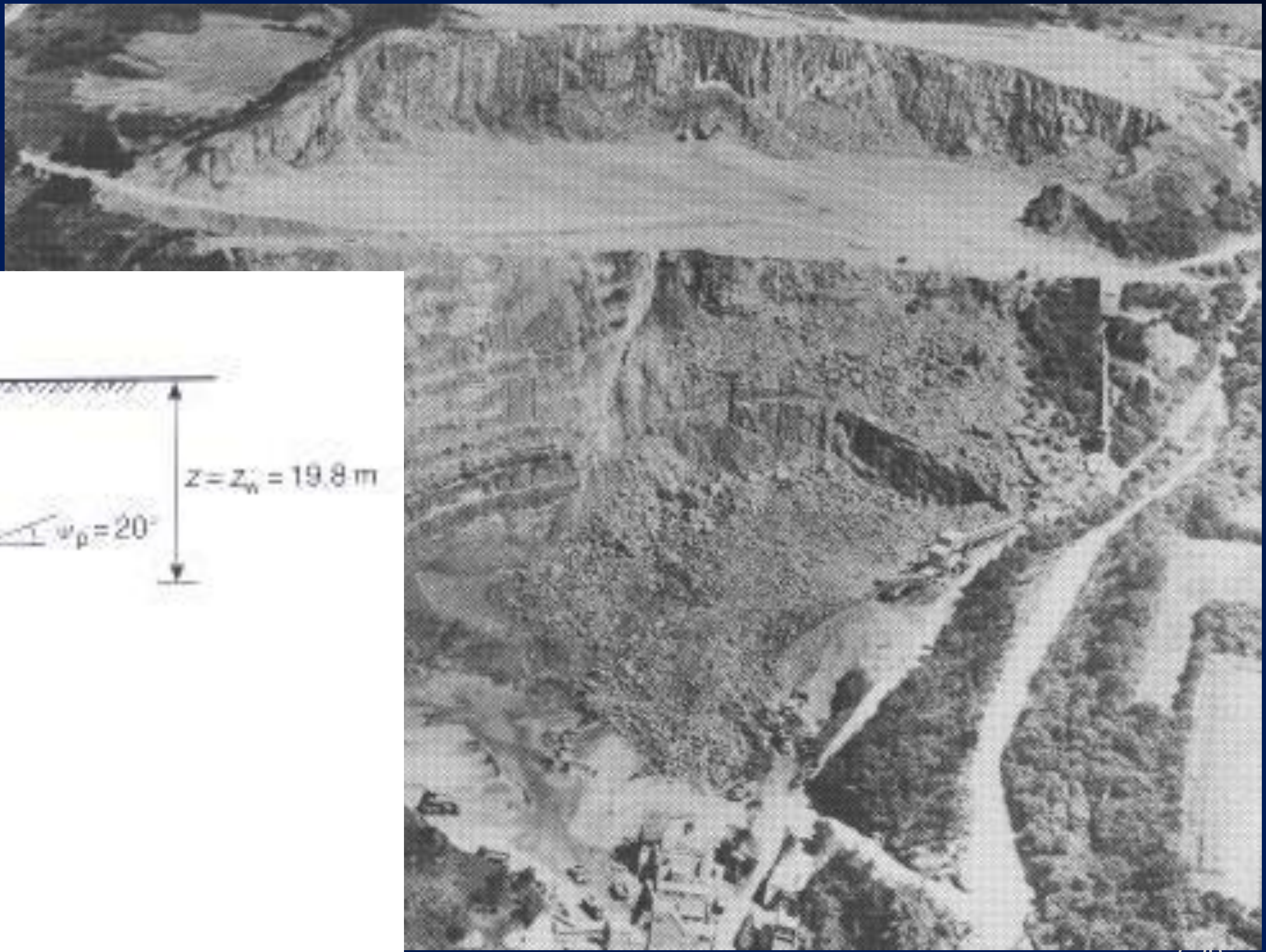
- **Strength Determined from Back Analysis of Slope Failures:**
  - Strength of Large Scale, In Situ Rock Mass
  - Figure 3.16 Shows Relationship Between:
    - Cohesion (c) and Friction Angle ϕ

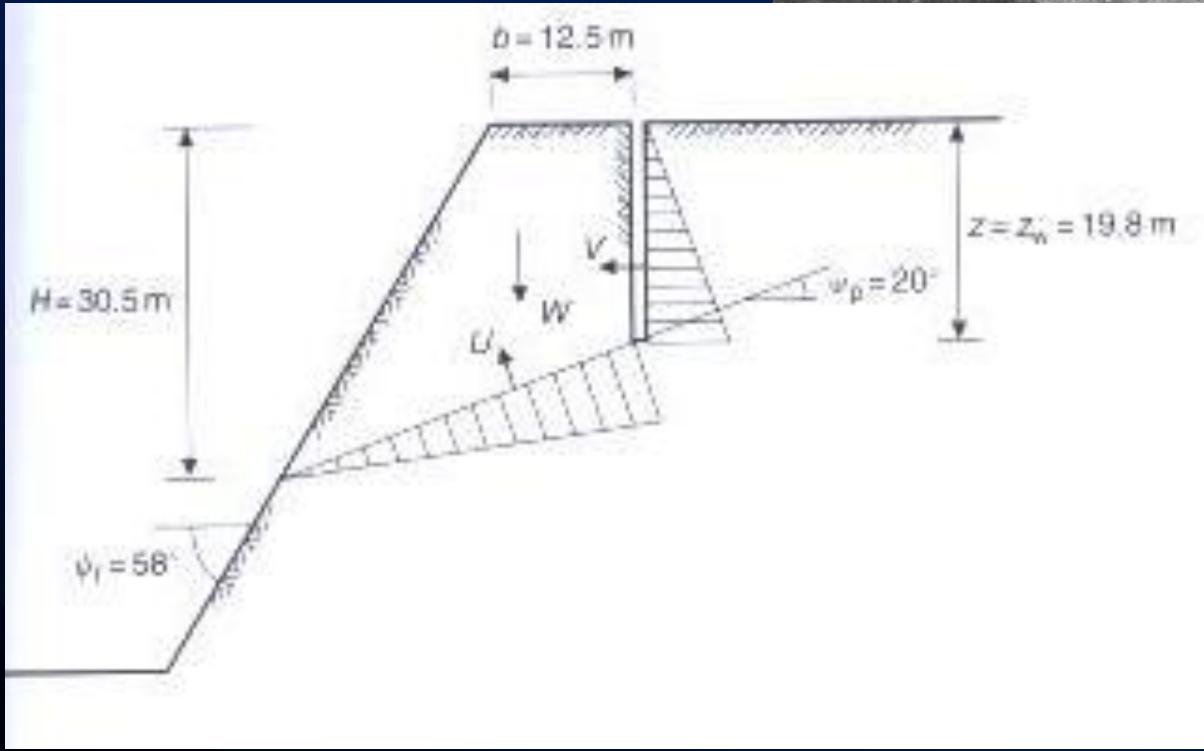
      &
    - Rock Mass Strength

      Weathering

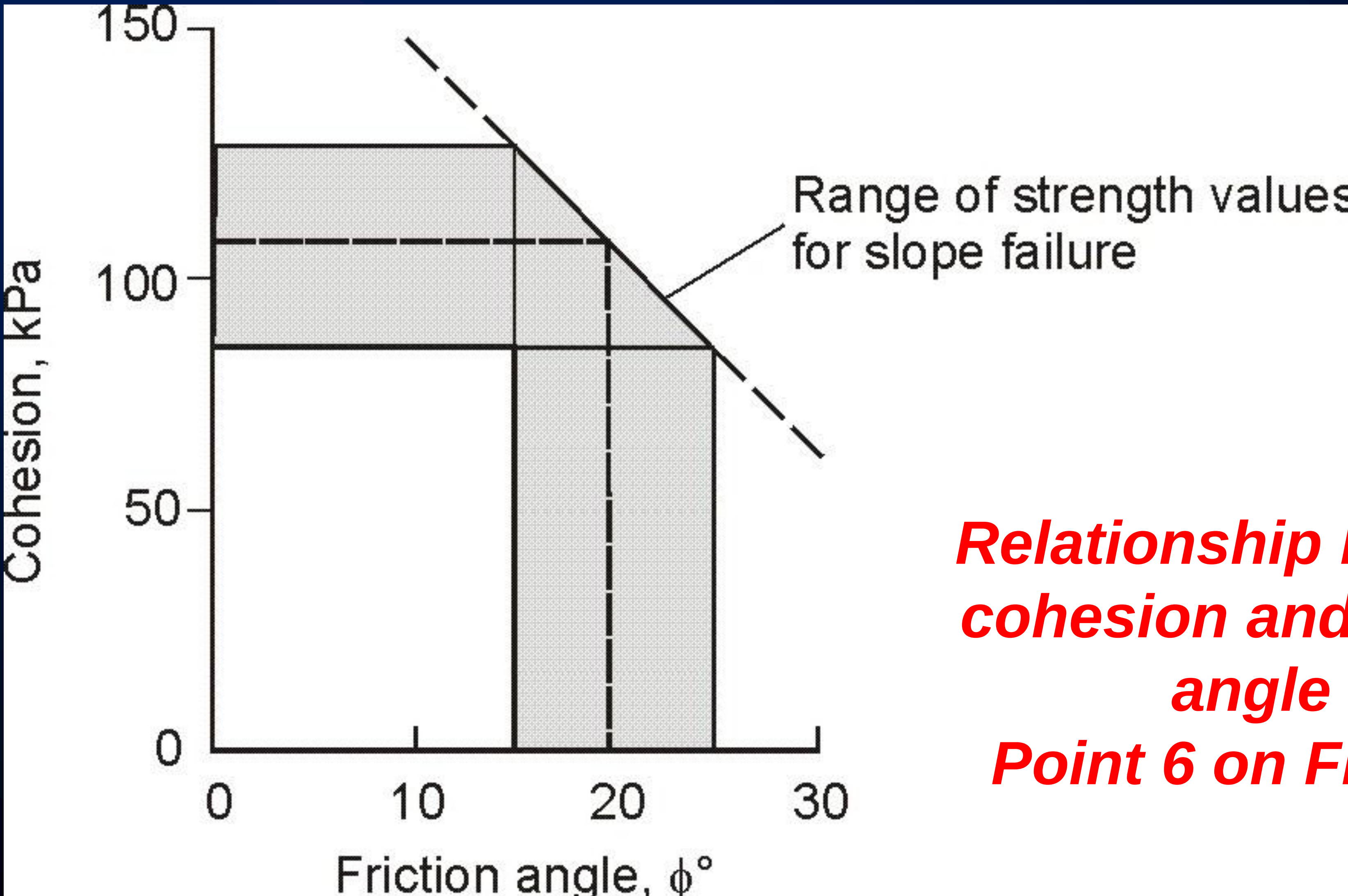
      Fracturing

Plane failure in limestone quarry on bedding planes dipping at 20º



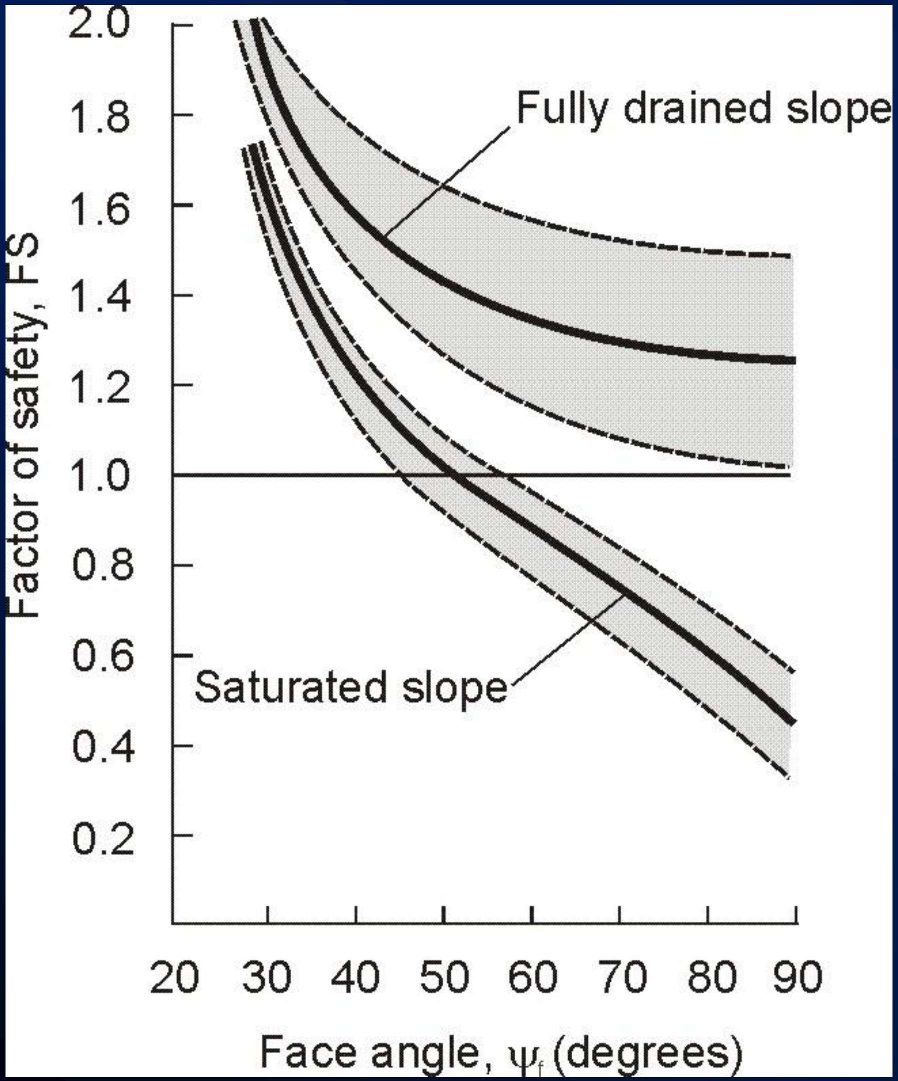


Back analysis of slope failure in limestone quarry



Relationship between cohesion and friction angle - Point 6 on Fig. 3.16

Back analysis of slope failure in limestone quarry



Factors of Safety calculated using shear strengths determined by back analysis

Shear Strength of Fractured Rock Masses by Back Analysis of Slopes

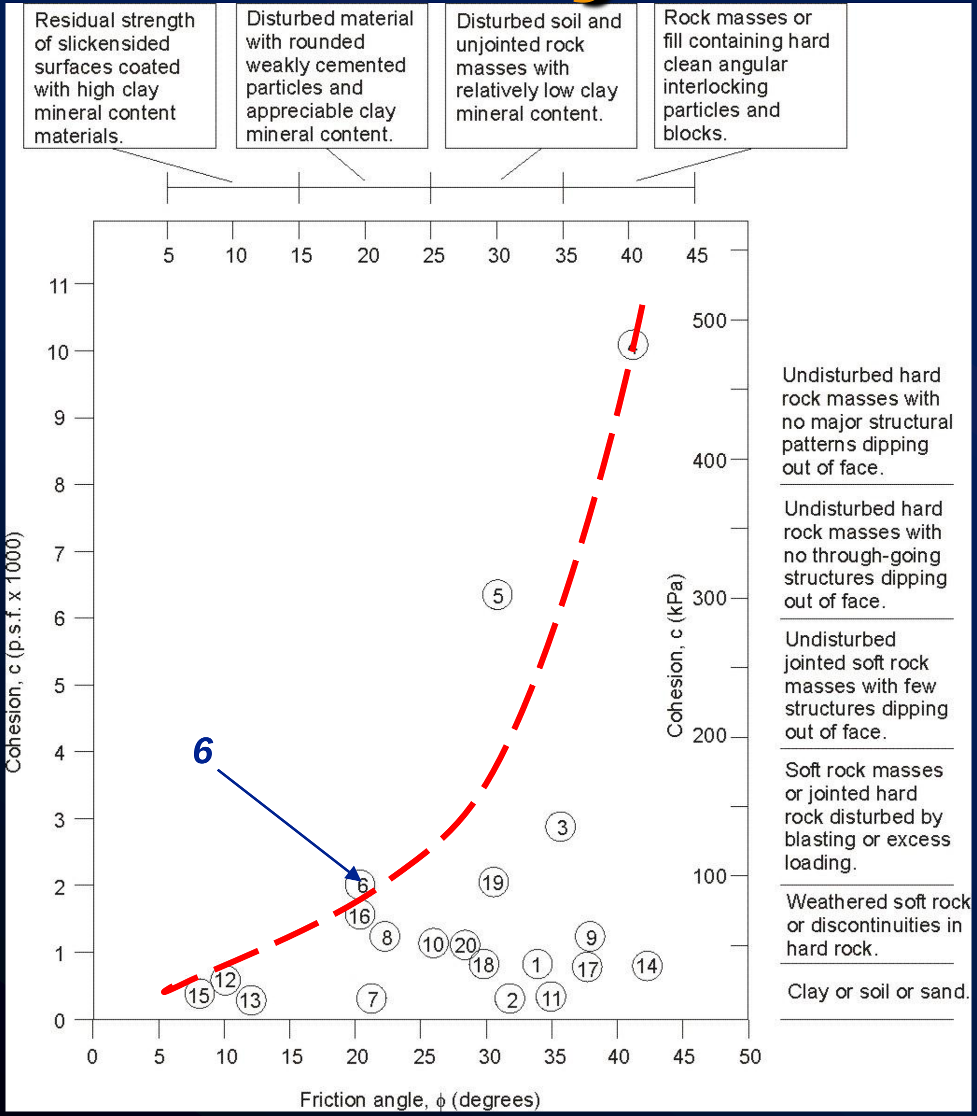
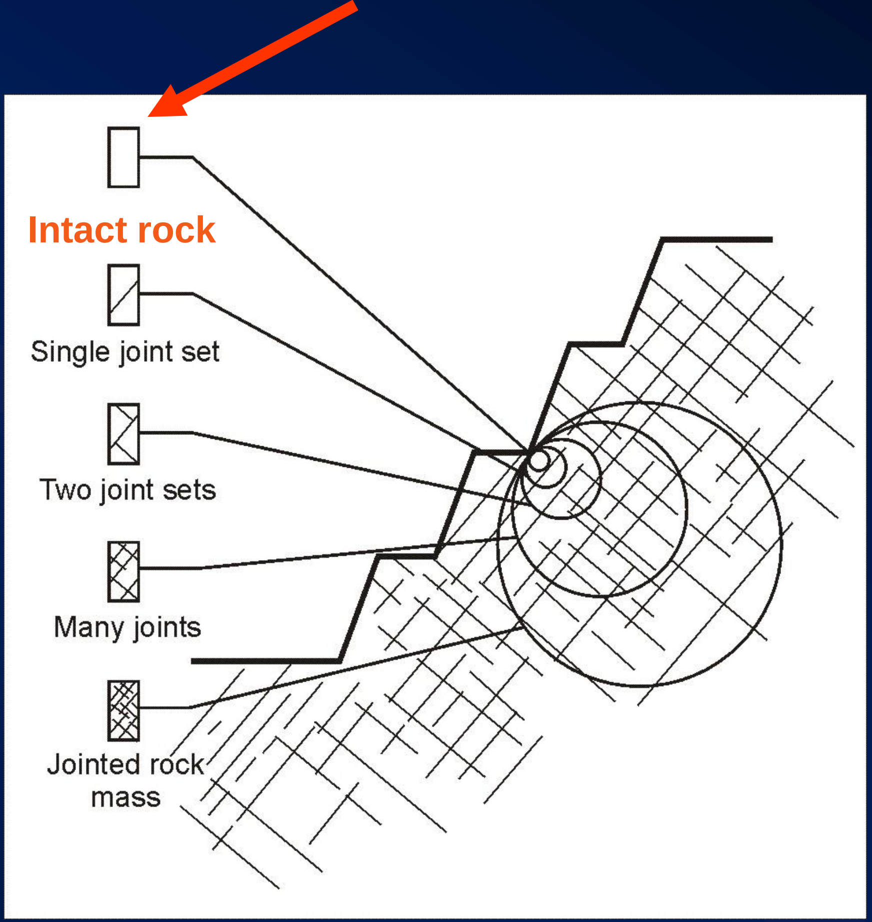


Figure 3.16

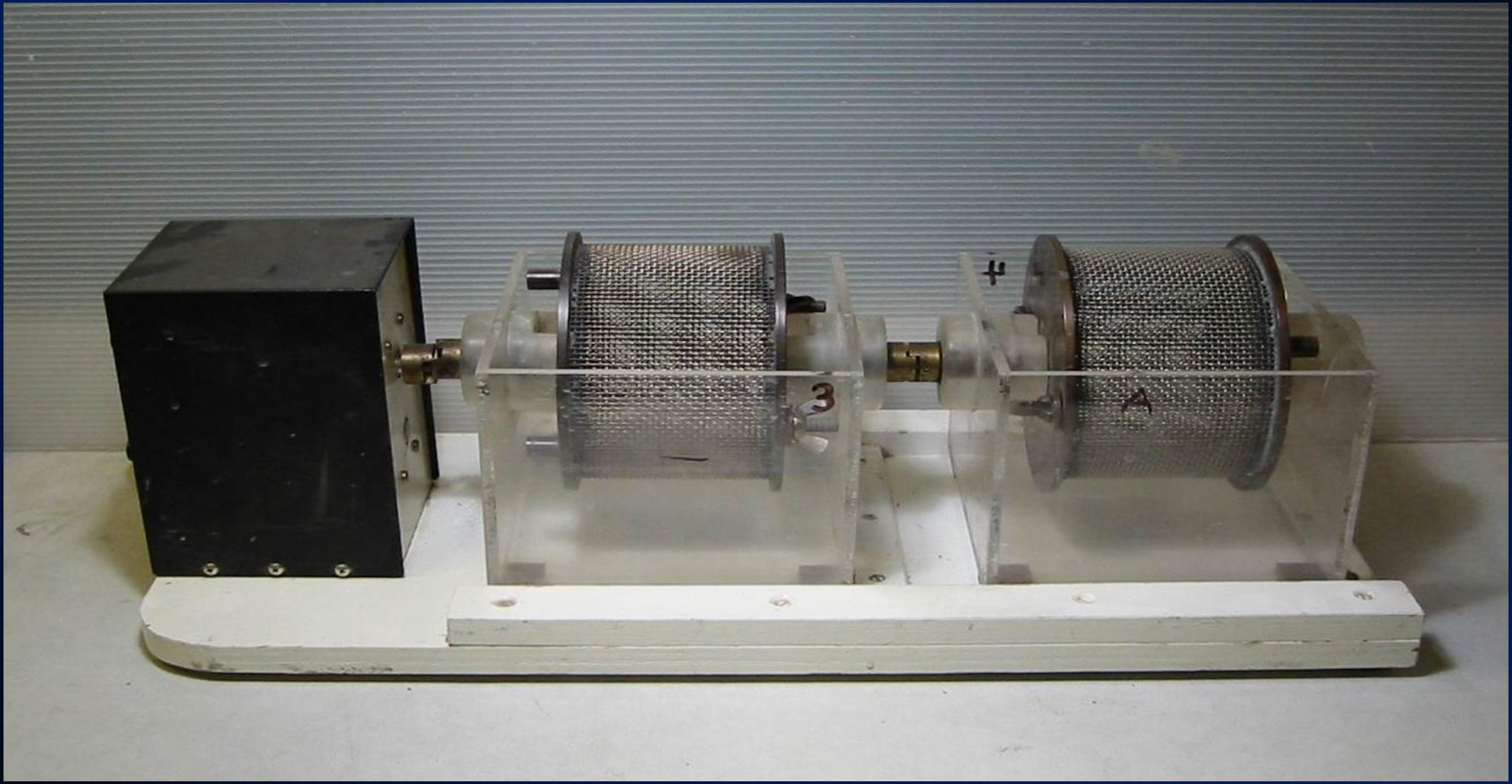
Rock descriptions on Table 3-2

Rock Durability and Compressive Strength

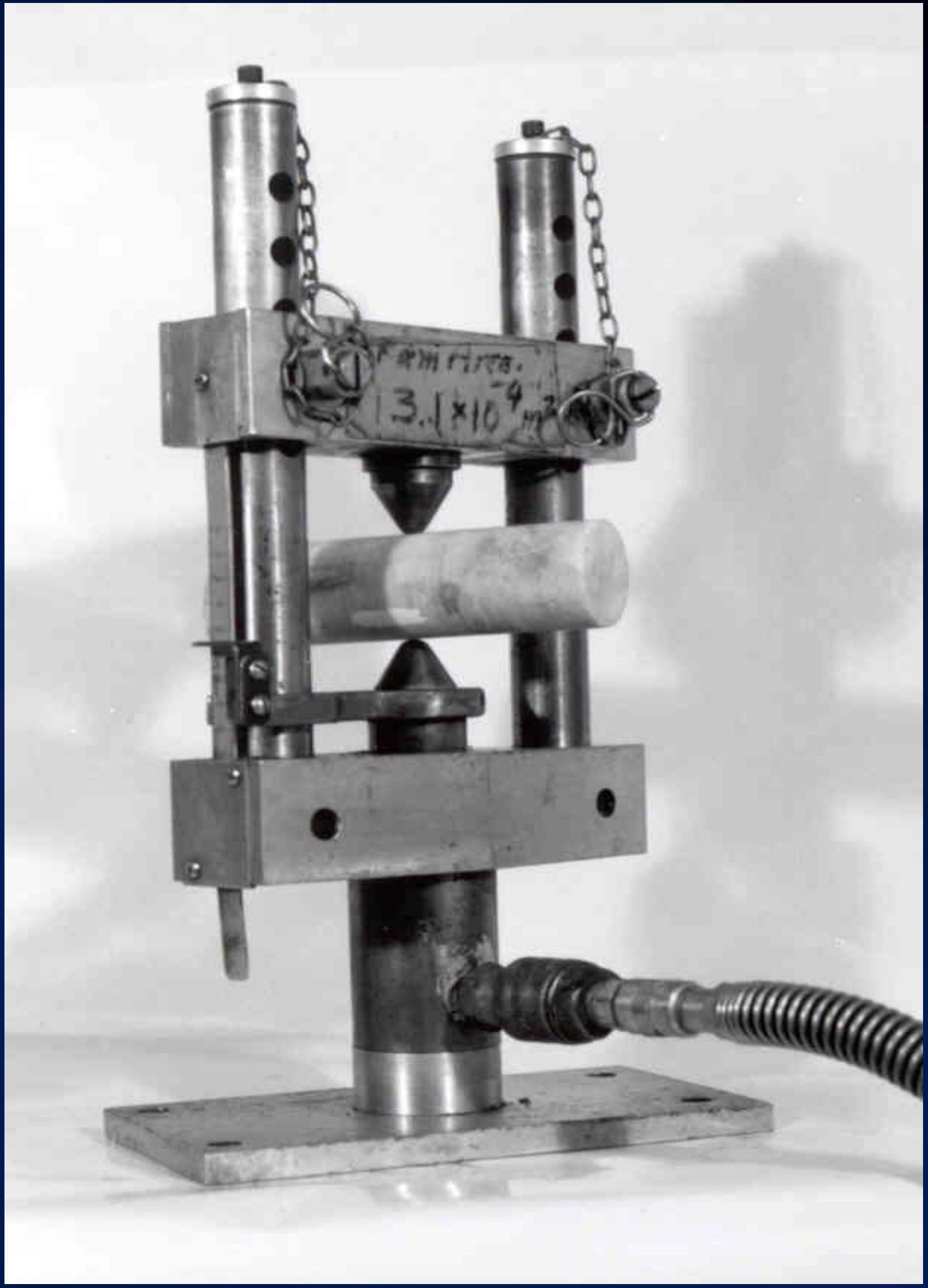
- *Slake Durability to Estimate Rate of Weathering*
- *Point Load Test to Estimate Compressive Strength*



Slake Durability to Estimate Rate of Weathering



Point Load Test to Estimate Compressive Strength



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- ***Evaluate Shear Strength of Discontinuities;***
- ***Evaluate Shear Strength of Rock Masses;***
- ***Evaluate Intact Rock Strength and Slake Durability.***